SPECIFICATION

Electronic Version 1.2.8

Stylesheet Version 1.0

FUEL CELL STACK AND FUEL CELL MODULE

Background of Invention

[0001] The invention relates generally to fuel cell stacks and modules for power generation, and more particularly, to fuel cell stacks and modules with segregated reactant streams.

[0002] Fuel cells, for example solid oxide fuel cells (SOFCs), are energy conversion devices that produce electricity by electrochemically combining a fuel and an oxidant across an ionic conducting layer. The fuel cell operating temperatures depend on the material forming the ionic conducting layer. Desirably, power generation systems incorporating high-temperature fuel cells have the potential for higher efficiencies and power outputs. Exemplary high-temperature fuel cells have operating temperatures above about 600 ^{o} C, and exemplary SOFCs operate in a range of about 800 to about 1000 degrees Celsius.

[0003] A typical fuel cell operates at a potential of less than about one (1) Volt. To achieve sufficient voltages for power generation applications, a number of individual fuel cells are integrated into a larger component. Separation of the oxidant and fuel streams is desirable for multistaging and the use of reactant products by other devices in a power generation system. For lower temperature fuel cells, for example having an operating temperature of less that about 200 ^{o} C, a large number of elastomer seals in compression may used to separate the two reactants. Elastomer seals cannot withstand the operating temperatures of high-temperature fuel cells, and consequently other materials, such as glass ceramics, must be used to form the seals. However, seal performance remains problematic for high temperature fuel cells, in particular for designs requiring sealing of cell edges or corners or for other joint

designs that require maintaining a gap of a certain size during thermal expansion and contraction cycles.

[0004] It would therefore be desirable to design a fuel cell stack that maintains separation of the reactant streams, using a reduced number of seals. It would further be desirable to incorporate the fuel cell stack into a fuel cell module having redundant current paths.

Summary of Invention

[0005] Briefly, in accordance with one embodiment of the present invention, a fuel cell stack includes a number of interconnects. Each interconnect defines at least two openings and includes at least one flow field for flowing a reagent. Each opening defines a respective fuel manifold, including at least one intake fuel manifold and at least one exhaust fuel manifold. The fuel cell stack further includes at least one fuel cell unit comprising an anode, a cathode, and an electrolyte disposed between the anode and the cathode. The anode is positioned adjacent to a respective one of the interconnects and is configured to be in both electrical connection and fluid communication with the respective interconnect. The flow field of the respective interconnect is configured to guide a fuel flow from the intake fuel manifold to the fuel exhaust manifold. The cathode is positioned adjacent to another respective one of the interconnects and is configured to be in both electrical connection and fluid communication with this interconnect. The flow field of this interconnect is configured to guide an oxidant flow across this interconnect. The fuel cell stack further includes a perimeter isolation seal disposed around the respective one of the interconnects adjacent to the anode. The perimeter isolation seal is disposed on a side of the interconnect facing the anode and is configured to seal the electrolyte to the interconnect. The fuel cell stack further includes at least two interior isolation seals disposed on the respective one of the interconnects adjacent to the cathode and on a side of the respective interconnect facing the cathode. One interior isolation seal surrounds each of the openings and is configured to seal the electrolyte to the respective interconnect.

[0006] A fuel cell module is also disclosed. The fuel cell module includes a vessel having an inlet and an outlet, which are configured to receive and exhaust an oxidant,

respectively. The fuel cell module also includes at least three fuel cell stacks arranged in a ring within the vessel. The fuel cell stacks separate an inner and an outer volume of the vessel, which volumes are in fluid communication through the fuel cell stacks. At least one of the fuel cell stacks has a fuel inlet, and at least one of the fuel cell stacks has a fuel outlet for receiving and exhausting a fuel flow, respectively. Each fuel cell stack includes at least two fuel manifolds, for receiving and exhausting the fuel flow, and at least one planar, high-temperature fuel cell unit comprising an anode, a cathode, and an electrolyte disposed between the anode and the cathode. Each fuel cell stack further includes a number of compressive seals for segregating the cathode and the fuel flow through the fuel manifolds and for segregating the anode and the oxidant. The fuel cell module also includes a number of electrical connections between the fuel cell stacks for electrically connecting each fuel cell stack to at least one other fuel cell stack.

Brief Description of Drawings

[0007] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0008] FIG. 1 illustrates a planar fuel cell unit in exploded view;

[0009] FIG. 2 depicts a fuel cell stack embodiment of the invention in cross-sectional view;

[0010] FIG. 3 shows an exemplary fuel cell module that includes a number of fuel cell stacks arranged in a rectangular configuration;

[0011] FIG. 4 is a top view of a hexagonal embodiment of the fuel cell module;

[0012] FIG. 5 depicts a number of electrical connections between two exemplary fuel cell stacks;

[0013] FIG. 6 is a top view of the fuel cell module of Figure 3;

[0014]

FIG. 7 shows another exemplary fuel cell module that includes a number of fuel

cell stacks arranged in a rectangular configuration;

[0015] FIG. 8 shows an exemplary electrical connection between two interconnects on neighboring fuel cell stacks; and

[0016] FIG. 9 depicts an exemplary sealing arrangement for the fuel cell unit of Figure 1.

Detailed Description

[0017] A fuel cell stack 10 embodiment of the invention is described with reference to Figures 1 and 2. As shown in Figure 2, fuel cell stack 10 includes a number of interconnects 22, each interconnect 22 defining at least two openings 24 in the plane of the interconnect 22, with each opening 24 defining a respective fuel manifold 25. As indicated in Figure 1 by arrows, the fuel manifolds 25 include at least one intake fuel manifold 251 and at least one exhaust fuel manifold 252. Although depicted in Figure 1 as being parallel in opposite directions, intake and exhaust manifolds 251, 252 may also be parallel in the same direction or perpendicular. For the particular embodiment depicted in Figure 1, each interconnect defines four, symmetrically arranged openings 24, which in turn define four fuel manifolds 25, for symmetric distribution of fuel within fuel cell stack 10. Each interconnect 22 also includes at least one flow field 34 for flowing a reagent, such as an oxidant or a fuel, across interconnect 22. Exemplary flow fields 34 are formed from metals that possess the requisite electrical conductivity, resist oxidation, maintain mechanical strength and are chemically stable under the operating conditions of the fuel cell. For example, for operating temperatures below 750–800 ^{O} C, the flow fields 34 could be stamped from metals compositions based on ferritic, stainless steels. Further, the exemplary flow fields 34 are fit into a channel in interconnect 22 or form an integral part of interconnect 22.

[0018]

Fuel cell stack 10 also includes at least one fuel cell unit 20 comprising an anode 26, a cathode 28, and an electrolyte 27 disposed between the anode and the cathode. Exemplary electrolytes 27 are impermeable with respect to both the fuel and the oxidant. For example, for proton exchange membrane (PEM) or SOFC fuel cells 20, exemplary electrolytes 27 are solid electrolytes 27, such as ion-conducting ceramic or polymer membranes. One exemplary planar fuel cell unit 20 is a solid oxide fuel cell

20, with an oxygen-ion conducting solid electrolyte, such as yttria stabilized zirconia (YSZ), ceria-doped zirconia, or lanthanum strontium gallium manganate (LSGM).

[0019] The anode 26 is positioned adjacent to a respective interconnect 22 and is configured to be in both electrical connection and fluid communication with interconnect 22. For the embodiment illustrated in Figure 1, flow field 34 supplies both the electrical connection and fluid communication. As indicated in Figure 1, the flow field 34 of this respective interconnect 22 is configured to guide a fuel flow from at least one intake fuel manifold 251 to at least one fuel exhaust manifold 252, over the surface of anode 26.

[0020] The cathode 28 is positioned adjacent to a respective interconnect 22 and is configured to be in both electrical connection and fluid communication with interconnect 22. As indicated in Figure 1, the flow field 34 of this respective interconnect 22 provides the electrical connection to cathode 28 and is configured to guide an oxidant flow across the interconnect 22 and over the surface of cathode 28. One exemplary oxidant is air.

[0021]

In addition, fuel cell stack 10 includes a perimeter isolation seal 44 disposed around the interconnect 22 that is adjacent to anode 26. For the particular embodiment shown in Figure 1, perimeter isolation seal 44 also extends inward between openings 24. As indicated in Figure 1, the perimeter isolation seal 44 is disposed on a side of the interconnect 22 that faces the anode 26 and is configured to seal the electrolyte 27 to the interconnect 22. Beneficially, perimeter isolation seal 44 shields anode 26 from the oxidant surrounding planar fuel cell unit 20. To shield cathode 28 from the fuel flow through fuel manifolds 25, fuel cell stack 10 also includes at least two interior isolation seals 45 disposed on the interconnect 22 adjacent to the cathode 28 and on a side of the interconnect 22 facing the cathode 28, as indicated in Figure 1. As shown, one interior isolation seal 45 surrounds each opening 24 and seals the electrolyte 27 to the interconnect 22. Beneficially, seals 44, 45 are compressive, as indicated in Figure 1, as compared to the edge seals (not shown) found on typical planar stack designs (not shown). By "compressive," it is meant that seals 44, 45 deform when placed in compression, either from the weight of the stack 10 or a mechanical means, such as tie bolts, to provide a better seal. In

order to generate a larger voltage across the stack 10, fuel cell stack 10 includes a number of planar fuel cell units 20 arranged in a vertical stack, according to a particular embodiment. As will be recognized by those skilled in the art, the particular configuration of three (3) planar fuel cell units 20 shown in Figure 2 is for illustrative purposes only, and the specific number of planar fuel cell units 20 included in the stack 10 will vary depending on the power requirements of the stack 10. For the particular embodiment illustrated in Figure 2, each of the two pairs of adjacent planar fuel cell units 20 shares an interconnect 22, with the interconnect 22 being adjacent and electrically connected to and in fluid communication with the anode 26 of one of the adjacent planar fuel cell units 20 and with the cathode 28 of the other adjacent planar fuel cell unit 20. For this particular embodiment, each of the interconnects 22, which is shared by the adjacent planar fuel cell units 20, includes a flow field 34 on each side of the interconnect 22, for electrical connection and to provide fluid communication for the adjacent anode 26 and cathode 28 of the neighboring planar fuel cell units 20.

[0022]

According to a particular embodiment, each planar fuel cell unit 20 is polygonal, as shown for example in Figure 1. Beneficially, polygonal configurations of fuel cell units 20 are relatively easy to manufacture and permit the minimal yet robust sealing arrangements discussed above. For example, corner stack seal 43, shown for example in Figures 3 and 4, need not be completely hermetic but must only provide sufficient resistance to the reactant flow through the stack 10 to maintain the separation of inlet and outlet oxidant flows. For example, corner stack seals 43 may be "leaky seals," that is non-hermetic seals designed with a higher flow resistance that that of fuel cell stacks 10, such that the majority of the fuel and oxidant flows through the fuel cell stacks, rather than through corner stack seal 43. Exemplary leaky seals are formed from a compressible cloth or a dense foam. In addition, the polygonal components may be stacked and arranged to form fuel cell stacks 10 prior to insertion in a vessel 62. Moreover, the fuel cell stacks 10 are self-aligning when stacked together due to the angles provided by the polygonal shape. For the fuel cell stacks 10 shown in Figure 3, each planar fuel cell unit 20 is rectangular. For the fuel cell stack 10 of Figure 1 and 4, each planar fuel cell unit 20 is hexagonal. More particularly, for the embodiment shown in Figure 1, each interconnect 22 defines four openings 24, which

are arranged in two pairs 50 positioned on two opposing ends 52 of the interconnect 22, each pair defining an intake fuel manifold 251 and an exhaust fuel manifold 252, as indicated by arrows in Figure 1. Beneficially, this configuration of openings 24 facilitates the symmetric distribution of fuel across the planar fuel cell unit 20. According to a more particular embodiment, the planar fuel cell unit 20 illustrated in Figure 1 is a polygonal solid oxide fuel cell 20.

[0023] In order to close the stack 10 and to collect electrical current from the planar fuel cell units 20, the fuel cell stack 10 embodiment shown in Figure 2, further includes a top end plate 12, which is disposed above an upper one of the planar fuel cell units 20, and a bottom end plate 14, which is disposed below a lower one of the planar fuel cell units 20. End plates 12, 14 are adapted for current collection, and exemplary top and bottom end plates 12, 14 are formed of ferritic stainless steel. In addition, end plates 12, 14 cap the fuel cell stack 10, preventing the fuel and oxidant from bypassing the fuel cell stack 10. The electric potential between the two end plates 12, 14 is the total voltage of the fuel cell stack 10 and equals the sum of the voltages of the individual cells 20.

[0024] According to a particular embodiment, the electrolyte 27 is impermeable to the reactants (hereinafter "substantially solid") and is deposited onto anode 26 and the respective one of the interconnects 22, for example by plasma spray, physical vapor deposition, or chemical vapor deposition techniques. For this particular embodiment, the perimeter isolation seal 44 comprises the electrolyte 27 and is formed by the deposition of the electrolyte 27 on the respective interconnect 22. An exemplary perimeter isolation seal 44 comprising electrolyte 27 is shown in Figure 9. For the embodiment of Figure 9, the electrolyte is thicker in an inactive area for sealing, than in the active area. The electrolyte 27 can be made thicker, for example by masking during the deposition process prior to assembly of fuel cell unit 20. Beneficially, this perimeter isolation seal 44, formed by direct bonding of the electrolyte 27 to the respective interconnect 22, is substantially planar and thus does not require maintenance of a certain gap size. The substantially solid electrolyte 27 may also be bonded to the anode 26, for example by sintering, with an intermediary layer (not shown) deposited to enhance the bond between the interconnect 22 and the electrolyte 27. Other exemplary seals 44, 45 comprise glass, glass ceramics, metal,

metal brazes, or combinations thereof deposited on the respective interconnect 22, for example, using one the deposition techniques listed above, to seal the electrolyte 27 to the respective interconnect 22. Beneficially, these seals 44, 45 are also substantially planar, thus obviating maintenance of a certain gap size.

[0025] A fuel cell module 60 is described with respect to Figures 3, 4, 5, 7 and 8. As shown in Figures 3 and 7, fuel cell module 60 includes a vessel 62 having an inlet 68 and an outlet 70, which are configured to respectively receive and exhaust an oxidant, for example air. Fuel cell module 60 further includes at least three fuel cell stacks 10 arranged in a ring within vessel 62. As shown in Figure 4, the fuel cell stacks 10 separate an inner and an outer volume 64, 66 of vessel 62, which are in fluid communication through the fuel cell stacks 10. At least one fuel cell stack 10 has a fuel inlet 72, and at least one fuel cell stack 10 has a fuel outlet 74, as indicated in top view in Figure 6, for receiving and exhausting a fuel flow, respectively. Each fuel cell stack 10 includes at least two fuel manifolds 25, for receiving and exhausting the fuel flow, and further includes at least one planar, high-temperature fuel cell unit 20. As used here, the term "high-temperature" fuel cell refers to a fuel cell having an operating temperature of at least about 600 degrees Celsius, for example a molten carbonate or solid oxide fuel cell. As discussed above, planar, high-temperature fuel cell unit 20 includes an anode 26, a cathode 28, and an electrolyte 27 disposed between the anode 26 and the cathode 28.

[0026] Each fuel cell stack 10 further includes a number of seals 44, 45 for segregating the cathode 28 and the fuel flow through fuel manifolds 25 and for segregating the anode 26 and the oxidant. Beneficially, seals 44, 45 are compressive, as indicated in Figure 1, as compared to the edge seals (not shown) found on typical planar stack designs (not shown).

[0027]

Fuel cell module 60 further includes a number of electrical connections 54 between fuel cell stacks 10 for electrically connecting each fuel cell stack 10 to at least one other fuel cell stack 10. For the exemplary embodiment shown in Figure 8, the electrical connections 54 are provided by the interconnects 22. Jumper wires 54 could also be used to provide the electrical connections 54 between fuel cell stacks 10, as indicated in Figure 5. Fuel cell stacks 10 may be connected in many ways, with

different voltages and redundancies. For example, if the stacks 10 are electrically connected pairwise in parallel, and the two pairs of stacks 10 are electrically connected in series in the fuel cell module 60 of Figure 3, then fuel cell module 60 provides a voltage equal to the sum of the voltages across a pair of connected stacks 10, with a two-fold redundancy, due to the parallel current path. Similarly, if all four stacks 10 are connected in parallel in the fuel cell module 60 of Figure 3, then the voltage supplied by fuel cell module 60 is limited to the voltage of a single stack 10, but the redundancy is four-fold.

[0028] According to a particular embodiment, vessel 62 is a pressure vessel 62. Using a pressure vessel 62 is beneficial, in that pressure vessel 62 is configured to force the oxidant through fuel cell stacks 10, such that the oxidant contacts the porous cathodes 28. Specific pressures vary with power generation applications. However, one exemplary pressure vessel 62 is configured to operate in a range of about three (3) to about ten (10) atmospheres. Beneficially, use of a pressure vessel 62 provides higher pressure reactants, to achieve higher fuel cell 20 voltages. For the particular embodiment illustrated in Figure 3, inlet 68 is configured to receive the oxidant into the inner volume 64 of vessel 62, and outlet 70 is configured to exhaust the oxidant from the outer volume 66 of vessel 62. For this embodiment, each planar, high-temperature fuel cell unit 20 is configured to convey the oxidant from the inner volume 64 to the outer volume 66 of the vessel 62. One benefit of the configuration shown in Figure 3 is that fuel in the pipes between the stacks 10 is heated by the hot exhaust oxidant flow. For the embodiment illustrated in Figure 7, the inlet 68 is configured to receive the oxidant into the outer volume 66 of vessel 62, and the outlet 70 is configured to exhaust the oxidant from the inner volume 64 of vessel 62. For the embodiment of Figure 7, each planar, high-temperature fuel cell unit 20 is configured to convey the oxidant from the outer volume 66 to the inner volume 64 of the vessel 62. This latter embodiment cools the stacks 10 with incoming oxidant flow. Beneficially, both of these configurations facilitate enclosing stacks 10 within vessels 62 similar to those currently designed for gas turbine applications.

[0029] Exemplary planar high-temperature fuel cell units 20 are described above with respect to Figure 1 and include interconnects 22 defining openings 24, which in turn define fuel manifolds 25, and including flow fields 34. As is also discussed above with

reference to Figure 1, for the exemplary planar high-temperature fuel cell units 20, the compressive seals 44, 45 include perimeter isolation seals 44 and interior isolation seals 45. For this embodiment, the electrical connections 54 are formed between interconnects 22, for example as shown in Figure 8, with at least two interconnects 22 in respective fuel cell stacks 10 being electrically connected. Alternatively, interconnects 22 in respective fuel cell stacks are connected with external connectors 54, such as jumper wires 54.

[0030] In order to generate larger voltages, in a more particular embodiment, each fuel cell stack 10 includes a number of planar, high-temperature fuel cell units 20 arranged in a vertical stack. As indicated in Figure 5, each planar high-temperature fuel cell unit 20 is disposed in a respective plane 90. For this embodiment, each electrical connection 54 is configured to connect interconnects 22 adjacent to at least two planar, high-temperature fuel cell units 20 in a respective plane 90, as indicated in Figure 5. The electrical connections 54 may be provided by interconnects 22, as shown in Figure 8. According to a more particular embodiment illustrated by Figure 2, at least one pair of adjacent planar, high-temperature fuel cell units 20 within each of the fuel cell stacks 10 shares a respective interconnect 22, with the interconnect 22 being adjacent to and in both electrical connection and fluid communication with the anode 26 of one of the adjacent planar, high-temperature fuel cell units 20 and with the cathode 28 of the other adjacent planar, high-temperature fuel cell unit 20. For this particular embodiment, each of the interconnects 22, which is shared by adjacent planar, high-temperature fuel cell units 20, includes a flow field 34 on each side of the interconnect 22, to electrically connect and to supply fluid communication for the adjacent anode 26 and cathode 28 of the neighboring planar, high-temperature fuel cell units 20. Further, as discussed above with reference to Figure 2, exemplary fuel cell stacks 10 include a top end plate 12 disposed above an upper one of the planar, high-temperature fuel cell units 20 and a bottom end plate 14 disposed below a lower one of the planar, high-temperature fuel cell units 20, for closing the stacks 10.

[0031] As noted above, the stacks 10 may be connected in a number of ways, depending on the desired power outputs and redundancies for fuel cell module 60. To provide a number of redundant current paths, in one embodiment the electrical connections 54 connect all of the planar high-temperature fuel cell units 20 within at least one of the

planes 90. For example, for the four stack 10 configuration of Figures 3 and 7, four electrical connections 54 connect the four planar, high-temperature fuel cell units in one plane 90, providing a fourfold current path redundancy but supplying a voltage limited to the voltage across a single one of the four stacks 10. To increase the voltage output of fuel cell module 60 while providing a twofold current path redundancy, for another embodiment, an electrical connection 54 connects a pair 80 of fuel cell stacks 10, and another electrical connection 54 connects a second pair 82 of fuel cell stacks 10, for the four stack 10 configuration of Figures 3 and 7. To maintain a constant output, when one fuel cell unit 20 fails to conduct, the current in the remaining stacks at the failed cell unit's level of the parallel path must increase accordingly. For example, for two cell units so linked, the current in the surviving cell doubles. For a six stack configuration, each of the surviving cells within the parallel path must carry an additional twenty percent (20%) more current. The minimum number of stacks so connected will thus depend on the amount of additional current that individual fuel cell units 20 can tolerate, which in turn depends in part on the type of fuel cells used.

[0032]

To transfer the exhaust of partially reacted fuel from one stack 10 to another stack 10, the fuel cell module 60 according to another embodiment, further includes at least one heat exchanger 56, which connects a pair 80 of fuel cell stacks 10. For Figure 3, exemplary pairs 80 include the pair of fuel stacks 10 that are labeled 1 and 2 and the pair of fuel stacks 10 that are labeled 3 and 4. Exemplary heat exchangers 56 include a pipe 56 and a pipe 56 equipped with heat exchange enhancement features, such as fins (not shown), and heat exchanger 56 is configured to supply the fuel flow exhausted from one of pair of fuel cell stacks to a second of pair of fuel cell stacks. For the arrangement shown in Figure 7, heat exchangers 56 are surrounded by oxidant from inlet 68, thereby beneficially cooling the exhaust fuel in pipes 56 and heating the oxidant entering the fuel cell stacks 10. In order to adjust the inlet temperature and fuel composition of the fuel entering the downstream stack 10 (for example, stack 2 in the stack 1 and 2 pair), more fuel may be added to the stream before it enters the down stream stack 10, for example as shown in Figure 7. For another embodiment, the fuel cell stacks 10 are designed such that fuel utilization in the upstream stack 10 (for example, stack 1 in the stack 1 and 2 pair) is modified with

respect to the fuel utilization in the downstream stack in order to optimize the overall fuel utilization obtained in the pair of stacks. Fuel utilization, namely the percentage of fuel passing through a given fuel cell unit 20 that is actually reacted by the fuel cell unit 20, is controlled using several design parameters, such as the distribution and concentration of reactants in the fuel cell unit 20.

[0033] For the particular embodiments of fuel cell module 60 shown in Figures 3, 6, and 7, fuel cell module 60 includes four fuel cell stacks 10 arranged in a ring and at least two heat exchangers 56, which connect the pair 80 of fuel cell stacks 10 and connect a second pair 82 of fuel cell stacks 10, respectively. For these embodiments, the planar, high-temperature fuel cell units 20 are rectangular, and each pair of fuel cell stacks includes a respective fuel inlet 72 for receiving the fuel flow and a respective fuel outlet 74 for exhausting the fuel flow. Exemplary planar, high-temperature fuel cell units 20 are planar SOFC units 20. In addition, fuel cell module 60 further includes a fuel feed line 76, which is configured to supply the fuel inlets 72, and a fuel exhaust line 78, which is configured to exhaust the fuel outlets 74. Fuel is supplied to fuel inlets 72, either prereformed or as a hydrocarbon, which is reformed within the stack, to form hydrogen (H_2) and carbon monoxide (CO). For example, the fuel is reformed within intake fuel manifold 251 or within the anode 26. In another example, the planar, high-temperature fuel cell units 20 incorporate an internal reformer (not shown) ahead of anode 26. Beneficially, reforming the hydrocarbon fuel within fuel cell units 20 enhances system efficiency.

[0034] Another embodiment of fuel cell module 60 is illustrated in Figure 4 in top view. For this embodiment, fuel cell module 60 includes six fuel cell stacks 10 arranged in a ring and at least four heat exchangers 56 connecting the pair 80 of fuel cell stacks 10, and connecting a second, a third, and a fourth pair 82, 84, 86 of fuel cell stacks 10, respectively, as indicated in Figure 4. As shown, the planar, high-temperature fuel cell units 20 are hexagonal. Exemplary planar, high-temperature fuel cell units 20 comprise planar SOFC units 20. Further, both the pair 80 and the second pair 82 of fuel cell stacks 10 include a respective fuel inlet 72 for receiving the fuel flow, and each of the third and fourth pairs 84, 86 of fuel cell stacks 10 includes a respective fuel outlet 74 for exhausting the fuel flow. In addition, fuel cell module 60 further includes a fuel feed line 76, which is configured to supply the fuel inlets 72, and a fuel

exhaust line 78, which is configured to exhaust the fuel outlets 74. Fuel is supplied to fuel inlets 72, either prereformed or as a hydrocarbon, which is reformed within the stack, for example the planar high-temperature fuel cell units 20 may incorporate an internal reformer (not shown) ahead of anode 26, to form hydrogen (H_2) and carbon monoxide (CO) from a hydrocarbon fuel. The stacks 10 may be connected in a number of ways, depending on the desired power outputs and redundancies for fuel cell module 60. For one embodiment, the electrical connections 54 connect two of the fuel cell stacks 10 together in parallel, connect another two of the fuel cell stacks 10 together in parallel, and connect the remaining two of the fuel cell stacks 10 together in parallel. For another embodiment, the electrical connections 54 connect three of the fuel cell stacks 10 together in parallel, and connect another three of the fuel cell stacks 10 together in parallel. In another embodiment, the electrical connections 54 connect each of the fuel cell stacks 10 together, to provide a six-fold current path redundancy. As discussed above, exemplary electrical connections 54 are formed between the interconnects 22 of the respective stacks 10.

[0035] Although only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. For example, it should be clear that the location of the fuel and air flow paths can be reversed, with the appropriate changes in the locations of the cathode and anode. Similarly, the fuel cell stack and fuel cell module could be assembled to have the oxidant internally manifolded and the fuel surrounding the stack. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.